EXECUTIVE SUMMARY

The objectives of this study were to:

1. Describe the species composition, catch-per-unit-effort (CPUE) and relative abundance (RA) of each fish species in Sullivan Lake;
2. Describe the age distribution and growth rates of each fish species;
3. Describe the food habits of each fish species and evaluate diet overlaps and competitive interactions between species;
4. Characterize the limnology of Sullivan Lake and determine if water quality, nutrient availability, primary or secondary production, and current lake management practices (e.g., drawdowns) limits fish production.

Previous limnology work by the Washington Department of Ecology (WDOE) and United States Geological Survey (USGS) classified Sullivan Lake as oligotrophic. Primary production was limited by low nutrient concentration, which resulted in exceptional water clarity (Dion et al. 1976; WDOE 1993,1994,1997). However, this sampling did not encompass an entire growing season. In the present study sampling occurred over an entire growing season (April-November) with the primary aim of relating limnology to fish production.

Previous fish surveys at Sullivan Lake were conducted by the Washington Water Power (WWP) Company in 1980 and 1990 (WWP 1980, 1990) and the Washington Department of Fish and Wildlife (WDFW) in 1994 (Mongillo and Hallock 1995; Bonar et al. 1997, 2000). These studies were relative abundance surveys that used only one sampling technique (gill nets set for a few nights during the summer). In the present study, fish were sampled monthly during the growing season (April-November) using a variety of techniques. Information was collected on relative abundance, age and growth, and food habits of each fish species to understand factors that affect fish production in Sullivan Lake.

Sullivan Lake is a high elevation (altitude = 787 m above sea level at full pool), deep (mean depth = 58 m, maximum depth = 101 m) lake, with a surface area of 5.6 km^2. Principle inlets, Harvey and Noisy Creeks, enter at the south end. The outlet drains out the north end into the Pend Oreille River via Sullivan Creek. In 1931, a 8.8 m high gravity dam at the outlet raised the lake's surface elevation to its present summer level. The lake is drawn down 6.1 meters to an altitude of 780.9 m in the fall (to release water for power production at 14 hydroelectric dams on the Pend Oreille River and Columbia River), and is refilled in spring. During the period that the lake is refilling (storing spring runoff) water retention time (WRT) was estimated to be 37 years. During the period that the lake was at its minimum surface elevation and maximum outflow (245 cfs), WRT was estimated at 1.4 years. This outflow included both stored water and influents from inlet tributaries: Harvey, Noisy and Hall creeks.

One purpose of the present investigation was to assess the effect of current water level fluctuations on the biological productivity of Sullivan Lake. The fall drawdown releases surface water that flushes nitrogen and phosphorus (which accumulated in the lake during the previous spring runoff) and carbon (fixed by photosynthesis into phytoplankton biomass during the previous summer growing season) from the lake. Zooplankton, which are concentrated at the north end of the lake are also flushed from the lake during the drawdown. As the drawdown coincides with establishment of fall turnover, when nutrients are suspended throughout the water column and phytoplankton and zooplankton are concentrated in the upper water column, loss of nutrients, primary producers and primary consumers may potentially be substantial. Thus, the loss of nutrients might be even greater than suggested by a relatively short WRT of 1.4 years. Additionally, annual drawdown, currently prevents establishment of periphton and benthic macroinvertebrate communities in the upper 6.1 meters of the lake.

Initial filling of the reservoir probably caused leaching of nutrients from inundated shorelines and temporarily increased productivity of the lake. However, it is typical for reservoirs to exhibit lower productivity after several decades, when the added nutrients have been assimilated and passed downstream (Hall 1971). It is probable that Sullivan Lake is less productive today than it was in pre-dam conditions.

Assuming that the lake surface were to be maintained constantly at the high (787 m) or low (780.9 m) elevations, water retention times ranged from 3.4 – 35 years at the low lake level and 3.7 – 37 years at the high level. Thus, it was apparent that maintaining the lake at a constant level reduced the flushing effect that occurs during the fall drawdown. This was reflected by an increase in minimum WRT from 1.4 to 3.4 – 3.7 years. Water retention time was greatest at the highest elevation (i.e., greatest lake volume) but the difference between the low and high elevations was minimal. Maintaining the lake constantly at either elevation would likely improve nutrient retention and increase primary and secondary production in comparison to the current operations. Additionally, a stable lake level, as opposed to annual dewatering, would promote colonization of the surface waters by periphyton and aquatic insects.

The fish community in Sullivan Lake is composed of 7 native (N) and 5 introduced (I) species:

Family	Name	Scientific Name
Cyprinidae	Speckled dace (N)	*Rhinichthys osculus* (Girard)
	Redside shiner(N)	*Richardsonius balteatus* (Richardson)
	Tench (I)	*Tinca tinca* Linnaeus
Catostomidae	Longnose Sucker (N)	*Catostomus catostomus* (Forster)
Salmonidae	Cutthroat trout (N)	*Oncorhynchus clarki* (Richardson)
	Rainbow trout (I)	*Oncorhynchus mykiss* (Walbaum)
	Kokanee (I)	*Oncorhynchus nerka* (Walbaum)
	Mountain whitefish (N)	*Prosopium williamsoni* (Girard)
	Pygmy whitefish (N)	*Prosopium coulteri* (Eigenmann & Eigenmann)
	Brown trout (I)	*Salmo trutta* Linnaeus
Gadidae	Burbot (I)	*Lota lota* (Linnaeus)
Cottidae	Slimy sculpin (N)	*Cottus cognatus* Richardson

We have records for stocking of 10,259,857 fish into Sullivan Lake between 1904 and 2003 by federal or state fisheries agencies. These included 2,578,297 cutthroat trout (282,883 identified as westslope cutthroat trout, *O. c. lewisi*; 5,200 as Yellowstone cutthroat trout, *O. c. bouveri*, and the remainder unspecified), 2,391,362 rainbow trout 4,985,614 kokanee, 9,980 Atlantic salmon (*Salmo salar* L.), 20,103 brown trout, and 265,501 brook trout (*Salvelinus fontinalis* L.). Additionally, burbot and tench were introduced illegally, respectively between 1990 and 1992 (Bonar et al. 2000) and after 1994 (tench were first discovered during the 2003 survey).

Kokanee (stocked from Lake Whatcom in 1913) developed a natural spawning run in Harvey Creek. Subsequent plants apparently failed to increase sport harvest, so kokanee plants were discontinued after 1945 and the population has been maintained by natural reproduction (except for incidental plants in 1976 and 2003). A recent genetic survey by WDFW indicated that the kokanee still maintain an affinity with Lake Whatcom stock kokanee (Young 2004).

At the time that kokanee run became established between 1913 and 1920 it was also observed that a natural run of adfluvial westslope cutthroat migrated into Harvey Creek (See Johnson 1914; Darwin 1916; Dibble and Kinney 1923). It is unknown to what extent planted cutthroat trout intermingled with the native cutthroat trout in Harvey Creek but a recent genetic survey by Trotter et al. (2001) found no evidence of introgression of genes from either Yellowstone cutthroat or rainbow trout into the Harvey Creek population, suggesting that the Harvey Creek cutthroat represented a native westslope cutthroat trout population. Genetic samples were obtained from cutthroat trout collected during the 2003 study to confirm this but the samples have not yet been analyzed by the WDFW Genetics Laboratory.

Plants of rainbow trout, Atlantic salmon, brown trout and brook trout failed to produce naturally self-sustaining populations. However, brown trout grew to large sizes in the lake. The Washington state record brown trout (10 kg) was harvested from Sullivan Lake in 1965.

Introduced burbot are growing well and reproducing successfully in Sullivan Lake. During the present study we collected several (n = 8) small burbot (30 – 150 mm TL), some of which were young-of-the-year. Genetic samples (n = 50) were collected from burbot during the 2003 study and turned over to the Idaho Department of Fish and Game (IDFG). The objective of the IDFG study was to characterize burbot populations throughout the Columbia River Basin, so we hoped our sample could be compared to other populations to determine the origin of burbot in Sullivan Lake. However, the samples are still being processed.

Three previous fish surveys were conducted at Sullivan Lake. In 1980, gill nets set by the Washington Water Power (WWP) company captured 15 fine-scaled sucker (species not identified), 3 cutthroat trout, 13 rainbow trout, 77 kokanee, 8 brown trout and 2 mountain whitefish. In 1990, gill nets set by WWP captured 13 suckers (species not identified), 14 cutthroat trout, 27 rainbow trout, 173 kokanee, and 12 whitefish (species not identified). In 1994, gill nets (n = 21) set by WDFW captured 74 total fish, including

1 speckled dace, 4 redside shiner, 27 longnose sucker, 2 cutthroat trout, rainbow trout, 11 kokanee, 2 brown trout, 3 mountain whitefish, 13 pygmy whitefish, and 8 burbot.

Creel surveys were conducted by WDFW in 1948 – 1951, 1954 – 1955, 1958, 1962 and 1965 – 1966. A total of 162 anglers interviewed caught 338 fish, comprised of 24% cutthroat trout, 12% rainbow trout, 56% kokanee, and 7% brown trout (WDFW File Data, Region 1, Spokane). Burbot were not observed in the creel before 1992 (Bonar et al. 2000) and 190 were caught by 30 anglers during a tournament in 1996 (Duff et al. 1997).

Limnological assessments, from April – November 2003, included:

1. Monthly water column profiles of temperature, dissolved oxygen, conductivity, and pH were made at 5 meter depth intervals at the deepest point in the lake using a Hydrolab Surveyor 3. Secchi disk transparency was measured and used to define the euphotic zone by multiplying the secchi depth by 3 (Lind 1979).
2. Water samples were collected monthly at 5 m depth intervals using a Van Dorn sampler. When the lake was stratified, composite samples were made of the epilimnion, metalimnion, hypolimnion by taking an equal amount of water form each depth sampled in the stratum. When the lake was isothermal, a single water column composite was made by the same method. Water quality assessment followed guidelines recommended by the American Public Health Association (APHA 1985). Water samples were stored on ice until analyzed within 24 hours by the Spokane Tribal Water Quality Laboratory, which is accredited by the WDOE and the Environmental Protection Agency (EPA). Each sample was analyzed for alkalinity (EPA 310.1) hardness (EPA 200.7) ammonia nitrogen (EPA 350.1) nitrate nitrogen (EPA 300.0), nitrite nitrogen (EPA 300.0), total nitrogen (EPA 351.1), orthophosphate (EPA 365.1), total phosphorus (EPA 365.4) and sulfate (EPA 300.0). The lab incorporates strict quality assurance/quality control procedures and samples in their analysis. In our lab, silica was determined (heteroply blue method) using a programmable spectrophotometer in a Hach DREL 2010 Advanced Water Quality Laboratory, total dissolved solids were measured using a Hach C0150 conductivity/TDS meter, and turbidity was measured using a Hach 2100P portable turbidity meter.
3. Water samples collected near the inlet and outlet of Sullivan Lake were screened for the presence of *E. coli* bacteria at the Spokane Tribal Laboratory using EPA method SM9213D.
4. Primary production was assessed by (a) measuring chlorophyll *a* in the epilimnion, metalimnion, and hypolimnion using a 10 AU Turner Designs Flourimeter and (b) the light/dark bottle method (Lind 1979). Each month light and dark bottles were suspended at the surface, middle and bottom of the euphotic zone. The method estimated net phytoplankton photosynthesis (NPP) based upon the difference between the initial dissolved oxygen present

and the amount generated after 24 hours in a light bottle (i.e.,which measured oxygen generated by phytoplankton photosynthesis minus oxygen consumed by plant and animal respiration). The dark bottle prevented sunlight from entering, so no photosynthesis occurred. Thus, the difference between the initial amount of dissolved oxygen present and the amount depleted after 24 hours measured plankton (plant and animal) community respiration (PCR). Adding NPP + PCR provided an estimate of gross phytoplankton photosynthesis.

5. Secondary production (consumers) was assessed by monitoring zooplankton and benthic macroinvertebrates. Zooplankton samples were collected monthly at the deepest points in the southern, middle and northern sections of the lake. Duplicate vertical tows were made from the bottom to the surface using a Wisconsin net (80µ mesh) to estimate densities in the water column. Duplicate tows were also made from a depth of 6 m to the surface at each location to estimate densities in the epilimnion. In the lab zooplankton were identified to the lowest taxon possible using a dissecting microscope and measured with an optical micrometer to nearest 0.1 mm (from the top of the head to the base of the carapace, excluding the spine). Biomass was estimated using length/weight regressions of Downing and Rigler (1984). Benthic invertebrates were collected using a Ponar dredge with 0.1 m^2 jaw opening at two sites each month. At each site, two samples were collected at depths <6 m and two additional samples were collected at depths of >6 m in an effort to determine the effect of the 6.1 m drawdown on benthic macroinvertebrate densities. In the lab, benthic macroinvertebrates were identified to family and enumerated. A paired t-test was used to determine if there was a significant difference in densities above and below 6.1 meters.

Fisheries assessments from April – November 2003 included:

1. Monthly adult fish surveys that sampled both shoreline and limnetic (pelagic) habitats. The lake shoreline was divided into 67 segments 200 m in length. Each month the mouths of the three inlet streams, plus 5-10 randomly selected shoreline sites were sampled using a Smith Root electrofishing boat. Standardized electrofishing transects of 10 minute duration covering a distance of 200 m were employed for each transect. About equal numbers of transects were made during the day and at night. Additionally, two horizontal gill nets (one sinking, the other floating) were set overnight (12-24 hrs) at each of two randomly selected shoreline sites each month. Each net was 61 m long x 2.4 meters deep with four panels of graded monofilament mesh (1.3, 2.5, 3.8, and 5.1 cm). Because Sullivan Lake has a steeply sloping shoreline, horizontal gill nets also sampled limnetic fishes. Baited minnow traps were set at three randomly selected shoreline sites from May to September. At each site 5-6 traps were deployed overnight (12-24 hrs). The limnetic zone was divided into 20 sections of approximately 400 m^2. Each month 3 – 4 sites were randomly sampled using vertical gill nets 2.4 m wide of varying depth

and mesh size. Nets were 30.5 m deep with 3.8 cm square mesh (n=2), 45.7 m deep with 2.5 cm square mesh (n=2), 45.7 deep with 5.0 cm square mesh (n=2), or 91 m deep with 6.4 cm square mesh (n=1). Records were kept of numbers, relative abundance, CPUE (fish/electrofishing hour, fish/net night, fish/trap night) and total length (mm) of fish captured by each method.

2. Age and growth studies for each species of fish were accomplished by recording lengths and weights of most fish collected during the above surveys. Additionally, scales were collected from ten individuals in each 10 cm length group of each species. Ages were determined by projecting the scale on a microfiche reader, and identifying alternating thick and thin growth rings that respectively represented summer and winter growth. Annuli were identified where winter rings exhibited "cutting over," i.e., where winter were truncated against the summer rings instead of extending completely around the focus of the scale. Fish lengths at the formation of each annulus were backcalculated using the Fraser Lee Method (Carlander 1969) or direct proportion method (LeCren 1947) and comparisons were made to growth of the same species from other water bodies to assess relative growth rates.

3. Stomach contents were collected monthly from a subsample of each species of fish to evaluate feeding habits. In the laboratory stomach contents were identified, enumerated, and weighed. Data were collected on the frequency of occurrence, percent composition by number, and percent composition by weight of each prey species in the diet of each fish species. These values (each of which ranged from 0-100%) were combined into a hybrid index of relative importance (IRI) that compensated for biases caused in using frequency of occurrence, numerical percentage and weight percentage to describe diets. Diet overlaps between species were calculated using the IRI values (Schoener 1971). Diet overlap calculations compared the proportions of each type of food item in the two species of fish. Overlap values ranged from 0 (no overlap) to 1 (complete overlap). Values less than 0.3 were considered low diet overlap and those greater than 0.6 were considered high overlap in an unproductive lake.

4. Several ancillary fisheries investigations were conducted in conjunction with our study. These included:

   - Backpack electrofishing and snorkel surveys conducted by the Kalispel Tribe in Harvey and Noisy Creeks. The purpose of these surveys was to determine the densities of cutthroat trout and ascertain if adfluvial migrations occurred between the creeks and Sullivan Lake (KNRD 2003).

   - A hydroacoustic and gill net survey conducted by WDFW from 23 – 26 September, 2003 (Baldwin and McLellan 2005). The objectives of the study were to evaluate the species composition, relative abundance, density and depth distribution of fishes occupying the limnetic zone of Sullivan Lake. Hydroacoustic transects were made using a sophisticated sonar system in combination with a computer program that identified individual fish targets of different sizes (Baldwin and McLellan 2005).

Gill nets (n = 51 sets) were used to assess the relative abundance of different species (and size classes) of limnetic fishes and these percentages were applied to the hydroacoustic fish targets counted to determine the population densities of each size class of each species. Two types of nets were used. Vertical gill nets 2.6 m wide by 46 m deep with each net with one mesh size (25, 38, 51, 64, 76, 89, or 102 mm stretch) and horizontal gill nets 2.6 m deep and 145.5 m wide with 70 equal sized panels of graded (25, 38, 51, 64, 76, 89, or 102 mm stretch). Gill net effort included vertical gill net sets (n = 28), floating (surface) horizontal gill net sets (n = 4), suspended (< 30 m) horizontal gill net sets (n = 11) suspended (> 30 m) horizontal gill net sets (n = 3).

- WDFW began to evaluate the status of the kokanee spawning run in Harvey Creek commencing in 2002 (McLellan 2003) and continued this work in 2003 and 2004 (McLellan 2004, 2005). This work was accomplished by making daily counts of kokanee spawners collected in a weir near the mouth of Harvey Creek and by making carcass counts of dead kokanee.

- A stable isotope analysis of Sullivan Lake aquatic organisms were conducted by EWU and KNRD in 2003 (Smith and Black 2004). Two stable isotopes of carbon (C_{12} and C_{13}) and nitrogen (N_{14} and N_{15}) exist in nature. Carbon fixed by benthic periphyton during photosynthesis contains more C_{13} than carbon fixed by limnetic phytoplankton. Relative trophic status of an organism can be detected by 3 – 4‰ (parts per thousand) increase in N_{15} between prey and predator, making it possible to trace limnetic and benthic fixed carbon through trophic levels in the food chain. This made it possible to evaluate the effects of drawdowns on the aquatic community. For example, benthic communities often cannot become well established in lakes with large annual drawdowns, so benthic carbon fixation is minimal. Thus, fishes that are normally thought of as benthivorous, such as suckers or burbot may be forced into a more pelagic existence as indicated by their presence in the food chain above phytoplankton and zooplankton instead of periphyton and benthic macroinvertebrates (see Black et al. 2003). At Sullivan Lake, Smith and Black (2004) evaluated stable isotopes in three species of zooplankton, 11 types of benthic macroinvertebrates and 10 species of fish to indicate the effect of drawdown on disrupting benthic carbon production.

- A creel survey was conducted by the Kalispel Tribe and EWU on 4 randomly selected weekdays and 3 – 4 randomly selected weekend/holidays per month from May – November 2003. Pressure estimates were made every 3 hours by driving around the lake and counting the number of shoreline and boat anglers. Angler interviews were conducted to determine the number of hours fished and the number of fish (by species) harvested. Lengths and weights of harvested fish were recorded. This information allowed us to determine the average weekday and weekend pressure by boat and shore anglers and the average harvest per unit effort (HPUE) in number of each species harvested per hour by anglers of each group. Multiplying these values allowed us to determine total catch and harvest during the days creel surveys occurred. Total fishing pressure, total catch and harvest (by species) for each month were estimated using the average fishing pressure and harvest rate determined from creel survey days that month and expanding these numbers to account for days when no creel surveys were conducted during that month. Monthly harvest estimates were summed to provide total numbers of each species harvested between May and November 2003.

Sullivan Lake was isothermal in April (4.8 ± 1.0° C) and November (5.7 ± 1.2° C) and stratified from May to October. The epilimnion was above 6 meters, the metalimnion between 6 and 15 meters and the hypolimnion below 15 meters. During periods of stratification, temperatures ranged from 11.9 to 22.4° C in the epilimnion, 6.5 to 11.5° C in the metalimnion and 4.2 -4.5° C in the hypolimnion. The eight month lake average was 14.0° C in the epilimnion, 7.7° C in the metalimnion and 4.5° C in the hypolimnion. Water quality standards in the Washington Administrative Code (WAC) suggest a rearing and migration temperature for salmonids of no more than 17.5° C. Preferred range (upper lethal temperature) reported in the scientific literature are 5.5 – 15.5 (21) ° C for cutthroat trout, 2.2 – 20.0 (23.9)° C for rainbow trout, 5 – 12.8 (23.1) ° C for kokanee salmon and 10 – 18.3 (29.4)° C for brown trout. Temperatures in Sullivan Lake were generally in the preferred range for salmonids. On a few occasions, surface temperatures were above the preferred temperature but temperatures in the lower epilimnion, metalimnion and hypolimnion were in the preferred range. Temperatures in Sullivan Lake did not limit salmonid production but would likely limit production of warm water species because the lake is too cold for good growth.

Mean (± SD) annual dissolved oxygen (D.O.) concentration was 9.6 ± 1.5 mg/L in the epilimnion, 9.4 ± 1.1 mg/L in the metalimnion and 9.0 ± 1.1 mg/L in the hypolimnion. Oxygen was usually at or near saturation levels. The lowest D.O. concentration measured was 7.5 mg/L, which was above the WAC minimum of 6.5 mg/L required to support salmonids. Dissolved oxygen did not limit fish production in Sullivan Lake.

Mean (± SD) annual pH was 7.9 ± 0.6 in the epilimnion, 7.7 ± 0.4 in the metalimnion and 7.7 ± 0.3 in the hypolimnion. The lowest pH measured (6.1) occurred in surface waters during June. This coincided with the spring freshet and was probably related to snow-melt runoff. Normal pH of rain and snow is about 5.5 – 6.0. Melting snow most likely caused the transitory depression in pH. The WAC criterion recommended a pH range between 6.5 and 8.5 for salmonids. The pH of Sullivan Lake was generally within this range and did not limit fish distribution.

Mean (± SD) annual conductivity was 104.7 ± 4.7 µs/cm in the epilimnion, 110.6 ± 5.3 µs/cm in the metalimnion and 113.1 ± 3.2 µs/cm in the epilimnion. Conductivity measures ionized nutrients such as ammonium ions (NH_4^+), nitrate (NO_2^{-2}), nitrite

(NO_2^{-3}) and orthophosphate (PO_4^-) that fertilize plant growth and is therefore a useful indicator of a lake's productivity. Most surface waters in the United States have conductivities that range from about 30 – 400 µs/cm (EPA 2000). Sullivan Lake is at the low end of this range. Lakes that support productive fisheries usually have conductivities that range between 150 – 500 µs/cm (EPA 2000). Sullivan Lake was below this range, indicating that fish production may be limited by low amounts of ionized nutrients.

Turbidity (± SD) was 0.6 ± 0.25 NTU (National Turbidity Units) in the epilimnion, 0.6 ± 0.31 NTU in the metalimnion, and 0.5 ± 0.24 NTU in the hypolimnion. Turbidity measures the amount of suspended particulates (e.g., sediment, phytoplankton, or zooplankton that scatter light) in the water. The highest turbidity recorded was 1.5 when sediments were washed into the lake by spring runoff. The WAC standard for turbidity was 5 NTU above background when the background is ≤ 50 NTU. Thus, Sullivan Lake was an exceptionally clear lake, which was further indicated by secchi disk transparency that averaged (ranged) 10.4 (7.1 – 15.8) meters. The euphotic zone (depth to which sunlight penetrated the lake and stimulated photosynthesis is approximately 3x secchi transparency) averaged (ranged) 31.0 (21.2 – 47.5) meters in Sullivan Lake. This compared to average secchi transparency (euphotic zone depth) of 5.0 (15.0) meters in Lake Coeur d'Alene, 6.5 (19.5) in Lake Pend Oreille and 8.0 (24.0) in Priest Lake, Idaho. Among lakes in Washington, only one (Crescent Lake, Clallam County) was less turbid. Secchi transparency and euphotic zone depth data indicated that Sullivan Lake was one of the clearest (most transparent) lakes in the Pacific Northwest and Continental United States. The high transparency was a reflection of the lake's low productivity.

Nutrients (nitrogen and phosphorus) were low in Sullivan Lake. Ammonia (NH_4^+), nitrite (NO_2^{-3}) and nitrate (NO_2^{-2}) are "free" forms of nitrogen that can fertilize phytoplankton (floating algae) and periphyton (filamentous algae attached to rocks). Total kjeldahl nitrogen (TKN) requires a digestion process and measures free forms of nitrogen in the water plus organic nitrogen that is tied up in plankton biomass. Ammonia and nitrite concentrations were continuously below detection limits (< 0.01 mg/L) throughout our study. Nitrate concentration was only occasionally detectable and averaged < 0.01 mg/L in each strata. Total kjeldahl nitrogen concentration (± SD) averaged 0.128 ± 0.52 mg/L in the epilimnion, 0.102 ± 0.044 mg/L in the metalimnion and 0.088 ± 0.035 mg/L in the hypolimnion. The data suggested that as soon as free forms of nitrogen entered the lake they were rapidly assimilated by phytoplankton or periphyton as the only measurable nitrogen was Kjeldahl nitrogen, which included organic matter. Nitrogen concentration was highest in October and November coinciding with fall turnover.

Orthophosphate (PO_4^-) is a free form of phosphorus that can fertilize phytoplankton and periphyton. Total phosphorus (TP) requires a digestion process and measures free forms of phosphorus plus organic phosphorus that is tied up in plankton biomass. Orthophosphate concentration (± SD) averaged approximately 3.25 ± 1.28 µg/L in the epilimnion, 2.88 ± 1.13 µg/L in the metalimnion and 2.88 ± 1.13 µg/L in the hypolimnion over the eight month study period and was occasionally below the detection limit of 2.0 µg/L (n = 2 of 20 samples). Total phosphate ranged from < 5 – 20 µg/L but was below the detection limit (5.0 µg/L) in so many analyzed samples (n = 11 of 20) that no meaningful average could be obtained. The average TP concentration was < 10 µg/L (i.e., <0.01 mg/L). Orthophosphate was highest in June and July (coinciding with runoff) and in October (when the lake started fall turnover). Both free nitrogen and free phosphorus were higher in October than November (when fall turnover was complete). This may be because nutrients were flushed out as the lake was drafted commencing in October. However, as no samples were taken of outflow water, this hypothesis was not tested in any direct way. The fact that concentration of both free nitrogen and free phosphorus were relatively low during spring (April) and fall (November) turnover periods (when they are often highest in other lakes) suggests that internal recycling of both elements during turnover is limited in Sullivan Lake. The annual fall drawdown may routinely flush nutrients from Sullivan Lake and contribute to the limited internal recycling of nitrogen and phosphorus.

Nitrogen and phosphorus are both used in the manufacture of biological macromolecules, particularly proteins, nucleic acids, and lipid membranes. Nitrogen is required for all three types of macromolecules but phosphorus is required only for nucleic acids and lipid membranes. As proteins are the most abundant type of macromolecule, the ratio of nitrogen to phosphorus for normal biosynthesis is usually about 7:1 to 10:1. Higher ratios (e.g., 11:1 to 14:1) indicate a deficiency of phosphorus in the lake, i.e., the lake is phosphorus limited because algae cannot make use of all the available nitrogen as there is insufficient phosphorus to achieve the balance between nitrogen and phosphorus to make biological macromolecules. In Sullivan Lake, we compared total nitrogen to total phosphate and found a ratio of ≥ 13:1 (0.13 mg/L TKN and < 0.01 mg/L TP), indicating that the lake is phosphorus limited (which is typical of oligotrophic lakes). However, if phosphorus levels were increased, the lake would quickly become nitrogen limited because nitrogen levels are so low.

Total nitrogen and total phosphorus in Sullivan Lake were compared to those in oligotrophic, mesotrophic and eutrophic lakes in Idaho, Montana and Washington. Values for Sullivan Lake were typical of other oligotrophic lakes such as Pend Oreille and Priest Lakes, Idaho, Flathead Lake, Montana and Lake Chelan, Washington and substantially lower than those of mesotrophic lakes (such as Davis, Deer, Loon, Osoyoos, Palmer and Roosevelt lakes, Washington) or meso-eutrophic lakes (such as Clear or Silver Lakes, Washington).

Nutrient limitation (oligotrophy) was a major factor that limits primary producers (phytoplankton and periphyton), primary consumers (zooplankton and aquatic insects) and secondary consumers (fish) in Sullivan Lake.

Ammonia, nitrites and nitrates can be toxic to aquatic organisms at concentrations above 10 mg/L, 0.2 mg/L, and 10 mg/L respectively. Maximum concentrations in Sullivan Lake were well below these levels, so they did not pose any toxicity threat to fish or other forms of aquatic life but do contribute to limiting growth of photosynthetic organisms.

Sullivan Lake was a moderately hard lake. Water column value for total hardness (± SD) averaged 54.3 ± 6.1 mg/L (as calcium carbonate – $CaCO_3$). Alkalinity (± SD) averaged 48.44 ± 1.7 mg/L (as $CaCO_3$). Total dissolved solids averaged 69.8 ± 10.9 ppm. None of these values posed any problems for survival and growth of aquatic organisms. Total sulfate (SO_4^{-2}) concentration averaged 3.69 ± 0.24 mg/L. Average values in the epilimnion, metalimnion and hypolimnion were respectively 3.40, 3.69 and 3.89 mg/L. Hydrogen sulphide (H_2S) produced by bacterial decomposition in bottom sediments was oxidized to sulfate, indicating an oxygenated microzone at the bottom of Sullivan Lake, which is characteristic of oligotrophic lakes.

Bacteria (*E. coli*) were detected in three of eight samples from Harvey Creek (two had 1 colony/100 ml, one had 7 colonies/100 ml) and one of eight samples collected at the outlet (1 colony/100 ml). WAC standards indicated that *E. coli* does not threaten aquatic life until colonies reach and average density of 100/100 ml with no more than 10% of samples exceeding 200 colonies/100 ml. *E. coli* did not pose a threat in Sullivan Lake.

Primary production was low in Sullivan Lake as indicated by low chlorophyll *a* concentration. Chlorophyll *a* is a pigment used by phytoplankton to capture the sun's energy for photosynthesis, so the amount of chlorophyll *a* present in the water is an indicator of the abundance of phytoplankton. During the eight month period of our study at Sullivan Lake mean monthly chlorophyll *a* values averaged (± SD) 1.23 ± 0.12 µg/L in the water column and were comparable to concentrations recorded in other oligotrophic lakes such as Pend Oreille (0.7 µg/L) and Coeur d'Alene (0.4 µg/L) Lake, Idaho, Flathead Lake, Montana (1.2 µg/L), and Lake Chelan, Washington (1.1 µg/L). Chlorophyll *a* concentration in Sullivan Lake was lower than reported for mesotrophic lakes such as Davis (2.9 µg/L), Osoyoos (3.2 µg/L) and Palmer (3.2 µg/L) lakes, Washington, meso-eutrophic Silver Lake, Washington (5.4 µg/L) or for eutrophic lakes such as Eloika (17.6 µg/L) and Sprague (36.3 µg/L) lakes, Washington.

The exceptional water clarity previously noted for Sullivan Lake indicated that phytoplankton were widely dispersed throughout a large euphotic zone. This observation, coupled with the low nitrogen and phosphorus levels accounted for the low chlorophyll *a* concentration. Chlorophyll *a* concentrations were high during spring turnover, declined in summer, increased in September and October until drawdown commenced.

Primary production in Sullivan Lake was so low that we had difficulty measuring the oxygen evolved during photosynthesis using the light/dark bottle method. In most months of our study we were unable to detect any difference in oxygen and concentration between pairs of light and dark bottles suspended at the top, middle and bottom of the euphotic zone. This meant that the amount of photosynthesis equaled the amount of respiration, so no or little net photosynthesis occurred. Only four of 21 pairs of samples evolved any net oxygen. Mean monthly oxygen evolved was a miniscule 0.08 mg O_2 per hour. The light/dark bottle method works best in eutrophic and mesotrophic waters where oxygen production and consumption are more evident; in oligotrophic lakes oxygen changes are often difficult to detect (Lind 1979). These results were consistent with other facets of our study which suggested Sullivan Lake is oligotrophic with limited primary production.

A trophic state index (TSI) value was calculated for Sullivan Lake by combining secchi disk transparency (m), chlorophyll *a* (µg/L) and total phosphorus (µg/L) into a single value (Carlson 1977). TSI values range from 0 to 100. Index values from 0 – 40 indicate oligotrophy. Monthly TSI values in Sullivan Lake ranged from 27 – 37 during the 2003 study. In 1989 and 1997, WDOE calculated trophic state index values of 30 and 27 respectively.

Secondary production (i.e., included primary consumers such as zooplankton that consumed phytoplankton and aquatic insects that consumed periphyton) was low in Sullivan Lake. This was indicated by low diversity, density and biomass of zooplankton, and low diversity and density of aquatic insects and benthic invertebrates.

A total of 126,719 zooplankton were examined in our study, comprised of only 5 taxa: 70% copepods (67% cyclopoids and 3% calanoids), 29% cladocerans (23% *Daphnia* sp., 6% *Bosmina* sp.) and 1% rotifers (all *Asplanchna* sp.). Black and Smith (2004) found one additional taxa of Cladocera (*Simocephalus*).

Mean (range) in monthly densities was 1,428 (1,105 – 2,251) cyclopoids/m^3, 36 (4 – 115) calanoids/m^3, 431 (14 – 1250) *Daphnia*/m^3, 83 (1 – 578) *Bosmina*/m^3, and 21 (<1 – 47) *Asplanchna*/m^3. Mean lengths (± SD) were 0.64 ± 0.25 mm for cyclopoids (n = 440), 1.11 (± 0.44) for calanoids (n = 359), 0.78 ± 0.26 for *Daphnia* (n = 428) and 0.33 (± 0.21) for *Bosmina* (n = 304).

The mean monthly zooplankton biomass averaged (ranged) 509 (183 – 822) µg/m^3. Monthly average zooplankton biomass was highest at the North end of the lake near the outlet averaging 568 µg/m^3 at the north site, 523 µg/m^3 at the middle site and 435 µg/m^3 at the south site. Monthly zooplankton biomass was highest in September (822 µg/m^3) and declined to 426 µg/m^3 after drawdown commenced in October. It is uncertain whether the drawdown or other factors (such as decreasing water temperature) contributed to the decline but in many lakes zooplankton biomass peaks with increased nutrient availability and phytoplankton during fall turnover. Hence, there is a good possibility that the zooplankton decline in Sullivan Lake can be attributed either to the declines in nutrients and phytoplankton that coincided with the drawdown, or the direct flushing of the zooplankton during the drawdown period (an attractive hypothesis since zooplankton biomass was most abundant in the outlet end of the lake). However, we did not test this hypothesis directly by monitoring zooplankton below the dam.

Densities of cladoceran zooplankton in Sullivan Lake were low in comparison to other northwestern lakes. Mean density of cladocerans in Sullivan Lake was 514/m^3 compared to 2,297/m^3 in Lake Roosevelt, 4,513/m^3 in Lake Chelan and 25,170/m^3 in Lake Pend Oreille. In 11 lakes used for comparison, only Lake Coeur d'Alene, Idaho had lower densities of cladocerans (250/m^3) than Sullivan Lake. It has been well documented that the low zooplankton density in Lake Coeur d'Alene is related to intensive size-selective cropping of large zooplankton by a large population of kokanee. Size selective predators reduced the average size (and fecundity) of *Daphnia* in Coeur d'Alene Lake, which caused the *Daphnia* population to collapse. The average (range in) size of *Daphnia* in Sullivan Lake was small [0.78 (0.4 – 1.4) mm] in comparison to six other lakes in Washington [1.26 (0.5 – 3.1) mm]. Zooplankton in Sullivan Lake were probably limited by low nutrient availability and primary (phytoplankton) productivity. It is also probable that a large population of kokanee crops off larger-sized *Daphnia* in Sullivan Lake, which affects *Daphnia* demographics (by lowering the average age and fecundity), thus contributing to the small size and low population levels of *Daphnia*.

Benthic macroinvertebrates (aquatic insects, crustaceans, snails and worms) were low in both diversity and abundance at Sullivan Lake. Between our study and that of Smith and Black (2004) only 14 taxa were found: round worms (Nematoda), water mites (Arachnida: Hydracarina), scuds (Crustacea: Amphipoda), two kinds of snails (Mollusca: Gastropoda), diving beetles (Coleoptera: Dytiscidae), midge (Diptera: Chironomidae), burrowing mayflies (Ephemeroptera: Ephemeridae), prongill mayflies (Ephemeroptera: Leptophlebiidae), water boatman (Hemiptera: Corixidae), water striders (Hemiptera: Gerridae), two kinds of dragon flies (Odonata: Anisoptera), damsel fly (Odonata: Zygoptera) and caddis flies (Trichoptera: Limnephilidae).

We collected six taxa by ponar dredge and Smith and Black (2004) collected the remainder by scuba diving. Because the bottom of Sullivan Lake was composed mainly of large cobble and rubble, which often prevented the jaws of the dredge from closing properly, our density estimates may be inaccurate.

We collected a total of 186 benthic invertebrates: 78 from < 6m in depth (above the drawdown point) and 108 from > 6m in depth (below the drawdown point). Densites averaged 143 organisms/m^2 above 6 meters and 161 organisms/m^2 below 6 meters. These differences were not statistically significant ($T = 0.38$, $P = 0.71$). However, in other area lakes where we have collected benthic invertebrates, the number in shallow water usually exceeds the number in deep water by a wide margin. For example, in Deer Lake (Stevens County) densities were 176 organisms/m^2 from shallow dredges compared to 80 organisms/m^2 from deep dredges and in Loon Lake (Stevens County) densities were 416 organisms/m^2 from shallow dredges compared to 80 organisms/m^2 from deep dredges (Scholz et al. 1987). Benthic invertebrate density averaged 3,721 organisms/m^2 at Sprague Lake, Adams and Whitman counties, (maximum depth of 6.1 m) (Taylor 2000) and 953 organisms/m^2 in Rock Lake, Whitman County (maximum depth of 106.6 m and bottom composed of rubble and cobble) (McLellan 2000). From these comparisons it was clear that Sullivan Lake was depauperate in aquatic insects and other benthic invertebrates.

The low diversity and density of benthic organisms in Sullivan Lake is probably related mainly to low nutrient levels and limited primary production. Many types of benthic organisms are primary consumers, grazing on periphyton attached to rocks. The annual drawdown likely disrupts periphyton production in the upper 6.1 m of the lake, which could partially account for the low number of benthic organisms near the surface. Additionally, because Sullivan Lake has high secchi disk transparency (deep euphotic zone) periphyton can grow at much greater depths than in other lakes. The interplay between these two factors could account for why benthic organisms are more abundant in deep water at Sullivan Lake.

A total of 3,280 fish was collected by electrofishing (effort = 15.2 hours or 91 ten minute transects), gill netting (effort = 72 net nights – 16 horizontal sinking nets, 16 horizontal floating nets and 40 vertical nets), and minnow traps (effort = 71 trap nights) in 2003. The number (n) relative abundance (RA) catch per unit effort (CPUE) and size range of each species captured by each method are recorded below:

Species[1]	Electrofishing			Horizontal gill net			Vertical gill net			Minnow traps			Total[2]		
	n	RA (%)	CPUE (#/h)	n	RA (%)	CPUE (#/net)	n	RA (%)	CPUE (#/net)	n	RA (%)	CPUE (#/trap)	n	RA (%)	Size range (mm)
RSS	1,575	77	104	39	9	1	0	0	0	687	92	10	2,301	70	12 -105
TNC	2	< 1	<1	3	<1	<1	0	0	0	0	0	0	6	<1	56-473
LNS	185	9	12	122	27	4	0	0	0	62	8.3	<1	372	11	11-440
CUT	19	< 1	1	31	7	1	1	5	<1	0	0	0	52	2	191-429
RBT	5	< 1	<1	7	2	<1	0	0	0	0	0	0	12	<1	104-420
KOK	66	3	4	204	45	6	2	10	<1	0	0	0	272	8	118-339
BRN	5	< 1	<1	3	<1	<1	0	0	0	0	0	0	8	<1	150-757
MWF	5	< 1	<1	8	2	<1	0	0	0	0	0	0	13	<1	105-443
PWF	0	0	0	0	0	0	1	5	<1	0	0	0	1	<1	116
BUR	185	9	12	37	1	1	17	81	<1	1	<1	<1	240	7	30-790
SSC	4	< 1	<1	0	0	0	0	0	0	0	0	0	4	<1	32-60
Total	2,051	100.0	138	455	100	12	21	100	<1	750	100	10	3,280	100	

[1]Redside shiner (RSS); Tench (TNC); Longnose sucker (LNS); Cutthroat trout (CUT); Rainbow trout (RBT); Kokanee (KOK); Brown trout (BRN); Mountain whitefish (MWF); Pygmy whitefish (PWF); Burbot (BUR); Slimy sculpin (SSC).
[2]One tench, 3 longnose sucker and 1 cutthroat trout caught in fyke nets were included in the total.

Redside shiner was the dominant fish collected by all methods (RA = 70.2%). Kokanee (RA = 8.3%), burbot (RA = 7.3%) and cutthroat trout (RA = 1.6%) were the dominant sport fish. Two species (tench and slimy sculpin) had not been reported in previous surveys. One species (speckled dace) previously reported in a 1994 survey by Mongillo and Hallock (1995) was not found in the 2003 survey.

According to Mongillo and Hallock (1995), Sullivan Lake was a stronghold for pygmy whitefish in 1994, when they accounted for 18% of the relative abundance (n = 13 of 74 total fish captured in 21 gill net sets). CPUE was 0.6 pygmy whitefish/net set. In the present study, we caught 1 pygmy whitefish in 476 total fish sampled in 72 gill net sets and WDFW caught 1 in 66 total fish sampled in 47 gill net sets (Baldwin and McLellan 2005). CPUE was 0.02 pygmy whitefish per net set. Although results were not strictly comparable because different nets and mesh sizes were used in the 1994 and 2003 studies, we believe that the difference represents a real decline in pygmy whitefish abundance in Sullivan Lake because more small sized mesh (the size that captured pygmy whitefish) was set in 2003 than 1994. We hypothesized that their decline may be related to the illegal introduction of burbot in about 1992 (Bonar et al. 2000). Bubot abundance has increased since that time while pygmy whitefish abundance appears to have declined.

Burbot were not reported in gill net surveys conducted at Sullivan Lake in 1980 and 1990. In 1994 burbot comprised 11% of the relative abundance (n = 8 of 74 total fish) captured in gill net surveys. CPUE was 0.4 burbot/net set. In our 2003 survey, burbot comprised 11.3% of the relative abundance (n = 54 of 476 total fish) captured in gill net surveys. CPUE was 0.8 burbot/net set. Comparative electrofishing CPUE data also indicated that Sullivan Lake harbors a relatively high burbot population in comparison to other lakes. CPUE for burbot was 12/hour in Sullivan Lake compared to 4/hour in Lake Roosevelt (EWU data), 0.6/hour in Bead Lake (EWU data), and <0.1/hour in Banks Lake (Polacek 2003). Collectively, these data indicated that burbot abundance has increased markedly in Sullivan Lake since they first appeared in 1992, so it is possible that burbot predation may be causing the decline in abundance of pygmy whitefish.

During hydroacoustic surveys a total of 66 fish (5 species) were captured by vertical and horizontal (surface, suspended or bottom set) gill nets set in the limnetic zone (Baldwin and McLellan 2005). Catch composition in order of relative abundance was comprised of 77% kokanee (n = 51), 12% cutthroat trout (n = 8), 8% burbot (n = 5), and 2% each pygmy whitefish and redside shiner (n = 1 each) (Baldwin and McLellan 2005). Fish less than 100 – 150 mm were not completely recruited to gill nets.

Fish abundance in Sullivan Lake was estimated (± SE) at 228,667 (± 80,244) targets 30 – 800 mm, including individuals greater (41%) or less (59%) than 150 mm (Baldwin and McLellan 2005). Based on the proportions of fish in gill net catches and sizes of hydroacoustic targets, kokanee abundance (± SE) was estimated at: age 0 (n = 103,821 ± 36,243), age 1 (n = 34,460 ± 12,093), age 2 (n = 22,220 ± 7,798), age 3 (n = 10,030 ± 3,520) (Baldwin and McLellan 2005). The abundance of age 0 kokanee, composed of fish < 30 – 150 mm, may have been overestimated because of unequal recruitment of smaller sized fish such as redside shiner to limnetic gill nets. Abundance of age 1 – 3 kokanee totaled about 67,000 fish (120 kokanee per hectare) and was thought to be reasonably accurate (Baldwin and McLellan 2005). Of these about 58 per hectare contributed to the fishery. Additionally, the lake appeared to harbor approximately 1,646 (± 577) age 2 – 4 adfluvial westslope cutthroat trout (250 – 300 mm). Other species were encountered too infrequently in pelagic gill nets to obtain accurate estimates. However, 3% of the 228,667 (± 80,244) acoustic targets represented fish greater than 300 mm TL (n = 6,860 ± 2,407). These would have represented longnose sucker, cutthroat trout, rainbow trout, kokanee, brown trout and burbot, the majority of which would have been burbot or longnose sucker. In EWU gill net and electrofishing surveys, 415 fish greater than 300 mm were captured, comprised of 56% burbot (n = 232), 33% longnose sucker (n = 135), 8% cutthroat trout (n = 33), ≈ 1% each kokanee, rainbow and brown trout (n = 5 kokanee, 5 rainbow trout, 4 brown trout), and <1% mountain whitefish (n = 1). Applying the burbot percentage to the hydroacoustic estimating yielded 3,842 ± 1,383 burbot > 300 mm (about 7 burbot > 300 mm per hectare). Burbot abundance likely exceeds this number by a substantial amount since they are often found in association with the bottom and consequently may not present a well-defined hydroacoustic target.

Backpack electrofishing and snorkeling surveys were conducted in the lower 0.5 km of Hall, Harvey and Noisy Creeks in April, May, June, July and October principally by the Kalispel Tribe Department of Natural Resources (KNRD) and augmented by EWU. No fish were collected or observed in Hall Creek. In Noisy Creek, 94 cutthroat trout (80 – 212 mm TL) were captured, including 55 young-of-the-year (YOY) < 50 mm (indicative that successful natural reproduction had occurred). Additionally, 22 yearlings, 12 2-year olds, 2 3-year olds and 3 4-year olds were collected. The lower 0.5 km of the Noisy Creek stream bed was dry from July to November. Most of the fish were collected above the dry segment.

In Harvey Creek, 44 cutthroat trout, 1 rainbow trout and 12 slimy sculpin were captured in the lower 0.5 km adjacent to Sullivan Lake. Cutthroat trout ranged from 64 – 368 mm TL. Four cutthroat trout (two sexually mature males and two sexually mature females) > 350 mm (age 4) were captured in June about 0.1 km above the bridge at the mouth and were likely adfluvial migrants from Sullivan Lake on their spawning migration. All remaining fish were ≥ 210 mm (ages 0 – 2), including 27 YOY < 50 mm (indicative of successful natural reproduction). A 1 km segment of the Harvey Creek stream bed was dry where the stream subsurfaced from the end of June to November. The dry bed segment was located upstream of a point about 0.1 km above the bridge at the mouth. KNRD also conducted snorkel surveys over the entire 15.6 km length of Harvey Creek from the headwaters to the mouth (Olson et al. 2003) by dividing the creek into 11 reaches of unequal size. Cutthroat trout were the only species observed. Densities ranged from 1 – 31 cutthroat trout/100 m^2, with the lowest densities near the mouth and highest densities near the headwaters. Average density of cutthroat trout in Harvey Creek was 9.2/100 m^2, which was comparable to or higher than densities reported for other cutthroat trout streams in Idaho, Montana and Washington [e.g., St. Joe River, Idaho had an average density of 1.4 cutthroat/100 m^2 (Thurow and Bjornn 1975)]. Collectively, these data indicated that Harvey Creek has a stable cutthroat trout population and that a segment of the population is adfluvial (migrating to and from Sullivan Lake).

The spawning run of kokanee in Harvey creek was estimated at 3,498 (2058 females, 1,440 males) in 2002 (McLellan 2003), 9,271 (4,409 females, 4,862 males) in 2003 (McLellan 2004), and 14,125 (7,517 females and 6,738 males) in 2004 (McLellan 2005). The 2002 count was likely underestimated because the trap was not installed until after the start of the spawning season (McLellan 2003). The 2003 and 2004 counts were thought to be reasonable approximations of the kokanee spawning population. The spawning population was composed predominately of four-year-old (age 3+) fish. At the present time it is uncertain if these data represented a trend towards increasing abundance or was indicative of a four year cycle of dominance as is common of many sockeye/kokanee populations. However, as abundance of kokanee spawners increased, the mean size of kokanee in the spawning population decreased. Mean lengths of sexually mature male and female kokanee were respectively 289 mm and 288 mm in 2002 (McLellan 2003), 273 mm and 265 mm in 2003 (McLellan 2004), and 251 mm and 242 mm in 2004 (McLellan 2005). Fecundity of individuals decreased corresponding to the decrease in size of females. Fecundity averaged 600 eggs/female in 2002 (McLellan 2003), 471 eggs/female in 2003 (McLellan 2004) and 351 eggs/female in 2004 (McLellan 2005).

Benthic carbon production in Sullivan Lake was likely disrupted by the annual drawdown. Black et al. (2003) found that the annual drawdown of Lake Roosevelt disrupted benthic carbon production by destabilizing the littoral zone and preventing colonization of the bottom by periphyton and benthic insects. In Lake Roosevelt, where the drawdown was ≥ 15 m annually, largescale suckers, burbot and sculpin respectively derived 68%, 100% and 77% of their carbon from pelagic sources (Black et al. 2003). Suckers were frequently observed on the surface feeding on zooplankton in foam lines. In contrast, at Banks Lake, where the drawdown was only 1 – 2 m, longnose suckers, burbot and sculpin respectively derived 18%, 30% and 0% of their carbon from pelagic sources (Smith and Black 2004). In Sullivan Lake, where the drawdown was intermediate at 6.1 m, longnose suckers, burbot and sculpins derived 54, 79 and 29% of their carbon from pelagic sources. Thus, it was apparent that Sullivan Lake had intermediate benthic carbon production as compared to Lake Roosevelt (extreme drawdown) and Banks Lake (minimal drawdown).

Sullivan Lake is oligotrophic, so light can penetrate below the drawdown point to support some benthic periphyton production. In our study, the depth of the euphotic zone averaged 31.0 meters (range 21.2 – 47.5 meters), which was deeper than the drawdown point (6.1 meters) and allowed some benthic carbon production as an energy source. However, light energy is attenuated at depth, so it was apparent that the annual drawdown of Sullivan Lake significantly reduced potential benthic carbon production by reducing colonization of the upper 6.1 meters by periphyton and benthic insects.

Creel surveys were conducted on 61 days between May 1 and November 30, 2003 principally by the Kalispel Tribe Department of Natural Resources and augmented by EWU. A total of 532 anglers interviewed caught 133 fish, comprised of 2% longnose sucker, 1% cutthroat trout, 3% rainbow trout, 93% kokanee and 1% burbot. Expanded estimates (± 95% confidence intervals) of angler pressure and fish harvest were 11,235 ± 1,067 angler hours, 71 ± 10 longnose sucker, 35 ± 5 cutthroat trout, 113 ± 11 rainbow trout, 3,526 ± 312 kokanee and 30 ± 4 burbot. Mean length (range) was 234 (195 – 271) mm for harvested kokanee (n = 71 measured), 293 (290 – 295) mm for cutthroat trout (n = 2) and 309 (307 – 310) mm for rainbow trout (n = 2). The average trip length was 3.5 hours, so about 3,121 angler trips were made. The number of angler trips was multiplied by a U.S. Fish and Wildlife Service estimate (adjusted for inflation) of the amount an average angler spent on a fishing trip in Eastern Washington ($29.32) to yield an estimated economic value of $91,507.72 for the Sullivan Lake fishery from May to November 2003.

Biological data were collected for each fish species found in the lake in 2003. Ages of redside shiners ranged from 1 – 5. At time of capture mean total lengths (TL) (± SD) and weights (± SD) were: Age 1 (70 ± 4 mm; 3 ± 1 g), Age 2 (81 ± 3 mm; 5 ± 1 g), Age 3 (92 ± 7 mm; 7 ± 2.8), Age 4 (100 ± 11; 9 ± 1 g), Age 5 (108 mm; 10 g). Mean lengths at annulus formation back-calculated from scales (n = 53) were 40 mm (age 1), 59 mm (age 2), 78 mm (age 3), 85 mm (age 4) and 102 mm (age 5). Redside shiner grew more slowly in Sullivan Lake than in Box Canyon Reservoir (Pend Oreille River, Washington) where Ashe and Scholz (1992) reported mean length at annulus formation of 48 mm (age

1), 71 mm (age 2), 94 mm (age 3), 122 mm (age 4) and 145 mm (age 5). The relatively lower growth rate in Sullivan Lake was probably related to the low primary and secondary production in Sullivan Lake. Sullivan Lake also had a shorter growing season in colder water than Box Canyon Reservoir, which reduced metabolic rate and food consumption.

Diet of redside shiner (n = 48) was comprised predominately of water mites (Arachnida: Hydracarina) and beetles (Coleoptera), which respectively accounted for 57 and 27% of the relative importance of the diet. Redside shiners also consumed midges (Diptera: Chironomidae), mayflies (Ephemeroptera), flying ants (Hymenoptera: Formicidae), and plants (periphyton and macrophytes). Stable isotope analysis revealed that redside shiner (n = 5) consumed 21% pelagically derived carbon (Smith and Black 2003). They likely get this from water mites, which were one trophic level above cladoceran zooplankton that consume pelagic phytoplankton. The stable isotope analysis indicated that the diet of redside shiner in Sullivan Lake was composed of mainly benthic origin (aquatic insects and snails).

Few redside shiners were caught in previous fish surveys at Sullivan Lake (n = 4 in 1994). Their high abundance (n = 2,301) in the present survey was most likely a reflection of the different survey methods used rather than an increase in the redside shiner population. Gill net CPUE was < 1 redside shiner per net night in both the 1994 gill net survey (Mongillo and Hallock 1995) and 2003 gill net survey but 104 were caught per hour of electrofishing and 10 were caught per minnow trap set in 2003. Redside shiner was abundant in shallow shoreline habitat and rarely encountered in limnetic habitats during the present study. They were often observed in close association with cobble and rubble substrate where they hid under or between interstices of rocks. Pulsed direct current electrofishing drew them out of these hiding places. Their small size and great abundance made redside shiner a suitable forage fish. They were found in the diets of piscivorous brown trout and burbot in Sullivan Lake in 2003.

Six tench captured during the 2003 study ranged from 56 – 473 mm TL indicating that several age classes were present in the lake. Ages were not determined and back-calculations were not performed. Two stomachs were collected for food habit analysis but neither contained any food. Stable isotope analysis revealed that tench (n = 2) derived 5% of their carbon from limnetic sources (Smith and Black 2004). Their position in the food chain indicated their diet included a mix of limnetic and benthic invertebrates (Smith and Black 2004).

Ages of longnose sucker ranged from 1 – 8. Total length and weight for each age class (mean ± SD) at the time of capture were: Age 1 (128 ± 22 mm, 24 ± 15 g), Age 2 (205 ± 36 mm; 110 ± 65 g), Age 3 (275 ± 56 mm; 271 ± 135 g), Age 4 (335 ± 41 mm; 391 ± 117 g), Age 5 (356 ± 15 mm; 477 ± 70 g), Age 6 (364 ± 32 mm; 496 ± 111 g), Age 7 (388 ± 21 mm; 581 ± 116 g), and Age 8 (407 mm; 658 g). Mean back-calculated lengths at annulus formation (n = 93) were: 93 mm (age 1), 164 mm (age 2), 214 mm (age 3), 259 mm (age 4), 292 mm (age 5), 302 mm (age 6), 339 mm (age 7) and 366 mm (age 8). Longnose sucker growth was slower in Sullivan Lake than in Box Canyon

Reservoir where Ashe and Scholz (1992) recorded mean back-calculated lengths at annulus formation of 122 mm (age 1), 170 mm (age 2), 244 mm (age 3), 302 mm (age 4), 366 mm (age 5), 429 mm (age 6), 460 mm (age 7) and 513 mm (age 8). The maximum size attained at age 8 was also smaller than the average (439 mm) for lakes in Montana (Carlander 1969). The slow growth rate in Sullivan Lake was ascribed to low productivity, cold water and a short growing season.

Diet of longnose sucker (n = 23) was comprised mainly of organic detritus (found in 76% of the stomachs examined), and chironomid (midge) larvae (in 56%) and pupae (in 36%). Longnose sucker also consumed roundworms (Nematoda), scuds (Amphipoda: Gammaridae), zooplankton (Cladocera), snails, beetles (Coleoptera), prongill mayflies (Ephemeroptera: Leptophlebiidae), flying ants (Hymenoptera: Formicidae), and seed pods. Stable isotope analysis revealed that juvenile (30 – 68 mm TL) longnose sucker (n = 5) obtained 37% of their carbon from the limnetic food base, primarily cladoceran zooplankton (*Daphnia*, and *Simocephalus*) (Smith and Black 2004). Periphyton, macrophytes and benthic invertebrates contributed the remainder of their diet. Adult (375 – 410 mm) longnose suckers (n = 5) relied on 54% limnetically derived carbon (Smith and Black 2004). This was probably obtained from their consumption of cladoceran zooplankton and mayflies. Results obtained by the stable isotope analysis and traditional food habit study were inconsistent, the former indicating prevalence of limnetic carbon, the latter indicating the prevalence of benthically derived carbon. These conflicting data may be reconciled if suckers consumed more zooplankton over the fall and winter when the lake was drawn down. The traditional food habit study did not sample much of that period whereas the stable isotope analysis integrates food consumed for up to one year. It was also possible that longnose sucker consumed limnetic organisms simply because not much shallow water habitat conducive to production of benthic invertebrates existed in Sullivan Lake, owing to its steeply sloping shoreline. The high relative importance of pelagic food (54%) in longnose sucker diet suggested by stable isotope analysis indicated that benthic production was limited and unable to support benthivorous fishes.

Gill net CPUE for longnose sucker was similar in 1994 (Mongillo and Hallock 1995) and 2003 surveys, respectively 2 and 3 per net night. In both years longnose sucker was the most abundant fish caught in gill nets. They were collected in both shoreline and limnetic habitats.

Ages of cutthroat trout ranged from 1 to 5. Total length and weight for each age class (mean ± SD) at the time of capture were: age 1 (153 ± 57 mm; 43 ± 47 g), age 2 (254 ± 40 mm; 178 ± 77 g), age 3 (323 ± 42 mm; 329 ± 96 g) and age 4 (355 ± 23 mm; 329 ± 96 g). The average condition factor was 1.0 ± 0.1 (n = 52). Mean back-calculated lengths at annulus formation (n = 52) were 124 mm (age 1), 205 mm (age 2), 275 mm (age 3), and 322 mm (age 4). Westslope cutthroat trout grew faster in Sullivan Lake than other lakes. For example, based on back-calculated lengths at annulus formation, cutthroat trout in Box Canyon Reservoir attained mean lengths of 83 mm (age 1), 145 mm (age 2), 221 mm (age 3), and 284 mm (age 4) (Ashe and Scholz 1992). Cutthroat trout in Priest Lake, Idaho attained mean lengths of 81 mm (age 1), 135 mm (age 2), 211 mm (age 3) and 284 mm (age 4). The mean condition factor of cutthroat trout in Sullivan Lake (0.98) was greater (slightly) than the national average of 0.92 (Carlander 1969), indicating that their weight gain was normal relative to their length gain. Relative weights of cutthroat trout in Sullivan Lake were reported by Baldwin and McLellan (2005). Their analysis indicated that Sullivan Lake cutthroat trout $\leq$ 350 mm TL were generally at or above the national standard for relative weight, whereas individuals > 350 mm TL were all below the national standard. These data were consistent with the hypothesis that food may be limiting growth (i.e., weight gain) in older age classes of cutthroat trout in Sullivan Lake.

Diet of cutthroat trout (n = 45) was comprised predominately of flying ants (Hymenoptera: Formicidae), which occurred in 60% of the stomachs examined and accounted for 86% by number, 57% by weight, and 68% of the relative importance in the diet. Cutthroat trout also consumed roundworms (Nematoda), spiders (Arachnida), snails (Gastropoda), beetles (Coleoptera), earwigs (Dermaptera), flies (Diptera), mayflies (Ephemeroptera), "bugs" e.g. water striders (Homoptera: Gerridae), aphids (Homoptera), moths/butterflies (Lepidoptera), dragonflies/damsel flies (Odonata: Anisoptera/Zygoptera), grasshoppers (Orthoptera) and fish. Stable isotope analysis indicated that 21% of the carbon in cutthroat trout came from limnetic sources. This was probably related to their consumption of aquatic insects (e.g., mayflies, damsel flies) that consumed limnetic rather than benthic prey. Both the traditional food habit analysis and stable isotope analysis indicated that cutthroat trout fed predominately on a variety of aquatic insects. Traditional food habit analysis also revealed that cutthroat trout also fed opportunistically on terrestrial flying ants and that these accounted for a substantial portion of the annual diet. Their reliance on flying ants, a food source not produced in the lake, may be a reflection of low food production in the lake.

Abundance of cutthroat trout in Sullivan Lake appeared to have declined from 1990 (WWP 1990) to 1994 (Mongillo and Hallock 1995) and from 1994 to 2003 (n = 14 captured in 10 net nights in 1990 = 1.4 cutthroat trout/net, n = 2 in 21 net nights in 1994 = 0.95 cutthroat trout/net and n = 32 in 72 net nights in the 2003 survey = 0.44 cutthroat trout/net). These differences appeared to be related more to sampling methodology (such as location of net sets and mesh sizes used) than population change. For example, in 2003 our gill net sets included 32 horizontal gill nets set along the shoreline and 40 vertical gill nets set in the limnetic zone. Thirty-one cutthroat trout were captured in horizontal gill nets (CPUE = 0.94 cutthroat trout/net) compared to only 1 in vertical gill nets (CPUE = 0.03 cutthroat trout/net). In 2003, WDFW caught 16 cutthroat trout in 51 horizontal and gill nets all set in the limnetic zone (CPUE = 0.31 cutthroat/net.) Thus, cutthroat trout in Sullivan Lake spent more time in the shoreline zone than the limnetic zone in 2003, which was consistent with the data regarding their food habits. In the 1994 survey, graded mesh size research gill nets (similar to ours) were set along the shoreline, so our CPUE for shoreline sets (0.94 cutthroat/net) in 2003 was nearly identical to the 1994 CPUE (0.95 cutthroat/net). Net mesh size and set locations were not described for the 1990 survey, so we were unable to compare data. Collectively, these data indicated that Sullivan Lake had a small but stable adfluvial population of cutthroat trout that spawned in inlet tributaries.

In contrast to the large numbers of age 0 and 1 cutthroat found in Harvey (n = 39 of 44) and Noisy Creeks (n = 77 of 94), the majority of cutthroat trout found in the lake (n = 49 of 52 or 94%) were age 2 (n = 17), age 3 (n = 28) or 4 age (n = 5). These data indicated that cutthroat trout may typically emmigrate out of tributaries into Sullivan Lake at age 2. The size difference of some 3 and 4 year old fish captured in the tributaries suggested that some cutthroat trout are adfluvial and some are resident life history forms. Four cutthroat trout > 350 mm captured in Harvey Creek were about the same size as 4 year old cutthroat trout in the lake (355 mm) and probably represented adfluvial life history form, whereas the three 4-year old cutthroat trout captured in Noisy Creek were much smaller (≤ 210 mm) than those found in the lake and probably represented the resident life history form.

Ages of rainbow trout ranged from 1 to 5. Total length and weight of each age class (mean ± SD) at the time of capture were: age 1 (104 mm; 10 g), age 2 (214 mm; 136 g), age 3 (261 ± 19 mm; 214 ± 6 g), age 4 (340 ± 50 mm; 363 ± 148 g) and age 5 (430 mm; 829 g). Mean back-calculated lengths at annulus formation (n = 10) were: 109 mm (age 1), 187 mm (age 2), 244 mm (age 3), 307 mm (age 4) and 387 mm (age 5). These lengths were generally less than attained at those ages in some lakes in northern Washington: Boundary/Box Canyon Reservoir where lengths were respectively 91/96 mm (age 1), 156/186 mm (age 2), 256/291 mm (age 3), 369/391 mm (age 4) and 538/526 mm (age 5) (Ashe and Scholz 1992; McLellan 2000). However, maximum total length was about the same as in some other lakes; e.g., Deer Lake, Stevens County where lengths were 196 mm (age 1), 259 mm (age 2), 295 mm (age 3), 302 mm (age 4) and 353 mm (age 5) (Scholz et al. 1987). The average condition factor of rainbow trout in Sullivan Lake was 1.06 which was within the normal range of 1.0 – 1.35 reported by Carlander (1969).

Diet of rainbow trout (n = 10) was comprised mainly of unidentifiable insect parts and flying ants which respectively accounted for 90% and 7% of the numerical percentage, 48% and 12% of the weight percentage and 40% and 17% of the relative importance in the diet. Rainbow trout also consumed spiders (Arachnida), snails (Gastropoda), beetles (Coleoptera), flies (Diptera), bugs e.g. water striders (Hemiptera: Gerridae), aphids (Homoptera), dragonflies/damsel flies (Odonata), and grasshoppers (Orthoptera). No rainbow trout were collected for the stable isotope analysis study. Rainbow trout often are planktivorous. In many northeastern Washington lakes, rainbow trout fed almost exclusively on large zooplankton such as *Daphnia*. Rainbow trout are known to be size selective predators of *Daphnia* > 1.3 mm (Galbraith 1967). Rainbow trout “filter feed” *Daphnia* by using their gill rakers as a strainer to divert the *Daphnia* down their gullet. *Daphnia* in Sullivan Lake averaged about 0.7 mm and were probably too small to collect on the gill rakers. Instead they passed through the spaces between their gill rakers and back into the water column.

Diet overlap analysis revealed that competition between members of the fish community in Sullivan Lake was low except that rainbow trout had relatively high diet overlaps with both cutthroat trout (0.64) and kokanee (0.61). These values indicated high potential for competitive interactions because the food supply of Sullivan Lake has been shown to be limited.

Rainbow trout abundance declined between 1990 and 2003. CPUE was 2.7 rainbow/net night in 1990 (n = 27 rainbow in 10 sets), 0.1 rainbow/net night in 1994 (n = 3 rainbow in 21 sets) and 0.1 rainbow/net night in 2003 (n = 7 rainbow in 72 sets). The higher abundance in 1990 can be attributed to stocking 168,500 rainbows in 1985 and 1986. No rainbows were stocked from 1987 – 1998. In 1999, 18,560 were stocked. None were stocked after that.

Ages of kokanee salmon ranged from 1 to 4. Total length and weight of each age class (mean ± SD) at the time of capture were: age 1 (168 ± 12 mm; 45 ± 10 g), age 2 (222 ± 28 mm; 103 ± 30 g), age 3 (251 ± 12 mm; 135 ± 19 g) and age 4 (286 ± 22 mm; 176 ± 35 g). Mean backcalculated lengths at annulus formation (n = 83) were: 110 mm (age 1), 173 mm (age 2) and 218 mm (age 3). Kokanee growth in Sullivan Lake was low in comparison to other oligotrophic lakes in the Pacific Northwest. Mean backcalculated lengths of kokanee in Pend Oreille and Priest lakes, Idaho respectively were 140/180 mm (age 1), 205/245 mm (age 2) and 242/290 mm (age 3) (Rieman and Myers 1992). In meso-oligotrophic Lake Roosevelt wild kokanee grew to 142 mm (age 1), 277 mm (age 2) and 391 mm (age 3). In meso-oligotrophic Lake Coeur d'Alene, kokanee grew to 161 mm (age 1), 192 mm (age 2) and 225 mm (age 3). Average condition factor of kokanee in Sullivan Lake (0.87) was lower than the typical range reported for kokanee in North America (0.95 – 1.05) reported by Carlander, signifying that they did not add the normal amount of weight per incremental change in length. Relative weight of kokanee collected in the hydroacoustic survey in Sullivan Lake in 2003 (n = 51) was consistently below the national standard across all total lengths and averaged 80% (range 50 – 90%) of normal (Baldwin and McLellan 2005).

Diet of kokanee (n = 68) was comprised mainly of zooplankton [in a numerical ratio of about 6 Cladocera (*Daphnia* sp.) to 4 Copepods], followed by flying ants (Hymenoptera: Formicidae) and midges (Diptera: Chironomidae). Zooplankton were found in 65% of the stomachs and accounted for 99% by number, 62% by weight and 64% of the relative importance of food items in the diet. Flying ants were found in 28% of the stomachs and accounted for 1% of by number, 14% by weight and 15% of the relative importance. Midges were found in 18% of the stomachs and accounted for < 1% by number, 16% by weight and 12% of relative importance. Kokanee also consumed spiders (Arachnida), beetles (Coleoptera), mayflies (Ephemeroptera), aphids (Homoptera) and pine needles.

Stable isotope analysis also revealed the importance of zooplankton in the diet of kokanee. Kokanee occupied a trophic position above copepods (which, in turn, occupied a position above cladocerans) and obtained 100% of their carbon from limnetic sources (Smith and Black 2004). The stable isotope analysis indicated copepods as a more important energy source for kokanee than cladocerans, whereas the traditional food habit analysis indicated the reverse. Increased consumption of copepods by kokanee during the winter months (when no stomachs were collected) could account for this difference.

Cladoceran densities and size influenced growth of kokanee in Sullivan Lake. Kokanee prefer to eat larger sized *Daphnia* if they are available. At Lake Roosevelt, Loon and Deer lakes, Washington, *Daphnia* comprised respectively > 90% (over a 10-year period based on index of relative importance), 74% and 99% (based on numerical percent) of kokanee diets (Scholz et al. 1988, Peone et al. 1990, Chichosz et al. 1999). In Odell Lake, Oregon, kokanee consumed 82% *Daphnia* by weight (Lewis 1971). At Sullivan Lake cladoceran densities averaged 514/m^3, average length of *Daphnia* was 0.78 mm and the average length of a 3 year old kokanee spawner was 251 mm. In Lake Roosevelt, cladoceran densities averaged 2,006/m^3, the average length of *Daphnia* was 1.51 mm and the average length of a 3-year old kokanee spawner was 448 mm (Cichosz et al. 1999). In Lake Coeur d'Alene, zooplankton density averaged 294/m^3, few *Daphnia* (all < 1.0 mm) were present, and the average length of a 3-year old kokanee spawner was 225 mm (Rieman and Meyers 1992; Scott 2002). The Coeur d'Alene kokanee population was stunted because their population is large, ranging from about 4 – 12 million. In Coeur d'Alene, kokanee have cropped large zooplankton by size-selective predation, which has reduced zooplankton fecundity and, hence, zooplankton populations. Fewer and smaller zooplankton have reduced kokanee growth. A similar situation was apparent at Sullivan Lake.

Kokanee can survive under these circumstances because they have long, finely spaced gill rakers that allow them to collect smaller zooplankton than other planktivorous fishes such as rainbow trout. This allows kokanee to subsist on copepods, which are usually smaller but more abundant than cladocerans in oligotrophic lakes.

Abundance of kokanee was variable at Sullivan Lake. In 1990, gill net CPUE was 17.3 kokanee/net night (n = 173 kokanee in 10 net sets). In 1994, CPUE was 0.5 kokanee/net night (n = 11 kokanee in 21 net sets). In 2003, CPUE was 2.9 kokanee/net night (n = 206 kokanee in 72 net sets). Part of this variability is undoubtedly related to differences in sampling methodology as previously noted in sections on other fish species. For example, in 2003, we captured 204 kokanee in 32 horizontal gill net sets (CPUE = 6.4 kokanee/net) but only 2 in 40 vertical gill net sets (CPUE = < 1 kokanee/net).

Landlocked kokanee/anadromous sockeye are known to exhibit a phenomenon called "cyclic dominance" usually on a four year cycle. During spawning runs, a low number of spawners is usually followed by a peak number of spawners the following year, then intermediate numbers during the next two years. This is thought to be related to density dependent mortality associated with low food supply in the oligotrophic lakes occupied by kokanee and sockeye. The year with low spawner abundance allows the food supply to recover, which reduces density dependent mortality the following year and results in increased survival. As the food supply gradually dwindles during the next several years the force of density dependent mortality reduces survival and lowers population levels. We suspect that cyclic dominance operates in Sullivan Lake because age and growth analysis indicated that kokanee growth was low in comparison to other oligotrophic lakes.

In 2003, kokanee spawning escapment into Harvey was estimated at 9,271 (nearly all age 4) kokanee (McLellan 2004) and harvest was estimated at 3,526 (age 3 and 4) yielding an approximate total run size of 12,797 kokanee. This was within the range of the hydroacoustic estimate (± 95% CI) of 10,030 ± 3,250 age-4 kokanee in Sullivan Lake. Collectively, these data indicated that essentially all of the kokanee spawning in Sullivan Lake occurs in Harvey Creek. We found no concrete evidence of shoreline spawning in the present study and the size of the cobble and rubble along the shoreline was much larger than the gravels typically used by kokanee as spawning substrate.

Densities of adult (age 3 and 4 kokanee) in Sullivan Lake, based on hydroacoustic data, were 58 kokanee/hectare (Baldwin and McLellan 2005). Rieman and Maiolie (1995) analyzed data from kokanee lakes in Idaho and found that when adult kokanee density exceeded 50 kokanee/hectare there was no corresponding increase in catch rate or yield to the fishery, which was possibly related to decrease in size of the kokanee. Hence, Baldwin and McLellan (2005) concluded that the Sullivan Lake kokanee population was "in the range of the ideal tradeoff between density and catchability," i.e., the fishery would not benefit from stocking more kokanee because the size will decline to the point where they either wouldn't be recruited to angling gear or anglers would lose interest in catching them because they are too small.

Ages of brown trout ranged from 1 to 11. Total length and weight of each age class (mean ± SD) at time of capture were: age 1 (150 mm; 29 g), age 4 (252 mm, 436 g), age 5 (345 mm; no weight recorded), age 7 (430 ± 11 mm; 779 ± 156 g), age 9 (645 mm; 3,873 g), age 10 (757 mm; 4,500 g). Mean backcalculated total lengths at annulus formation (n = 8) were: 102 mm (age 1), 142 mm (age 2), 183 mm (age 3), 235 mm (age 4), 294 mm (age 5), 372 mm (age 6), 437 mm (age 7), 544 mm (age 8), 621 mm (age 9) and 669 mm (age 10). Brown trout in Sullivan Lake initially grew more slowly than in other lakes but their growth eventually (at about age 8) surpassed that of other populations. For example, backcalculated lengths of brown trout in Boundary Reservoir were 114 mm (age 1), 178 (age 2), 273 mm (age 3), 351 mm (age 4), 397 mm (age 5), 494 mm (age 6) and 550 mm (age 7) (McLellan 2000). Backcalculated lengths of brown trout in Box Canyon Reservoir were 89 mm (age 1), 155 mm (age 2), 229 mm (age 3), 300 mm (age 4), 366 mm (age 5), 396 mm (age 6), 455 mm (age 7), 478 mm (age 8) and 519 mm (age 10) (Ashe and Scholz 1992)

Diet of brown trout (n = 4) consisted predominately of redside shiner, which occurred in all (100%) of the stomachs and accounted for 37% by number, 74% by weight, and 45% of the relative importance of food items in the diet. Redside shiner was the only species of fish that was found in brown trout stomachs. Brown trout also consumed aphids (Homoptera), moths/butterflies (Lepidoptera) and grasshoppers (Orthoptera). Stable isotope analysis revealed that brown trout (n = 3) consumed 37% limnetic carbon. They had a trophic position of a top carnivore, over the trophic positions of redside shiner, sculpin and longnose suckers. The large size of brown trout in Sullivan Lake was most likely related to the high relative abundance of redside shiner.

Brown trout accounted for 12% of the relative abundance in gill nets set by WWP in 1980 (n = 8 brown trout in 77 total fish) and 8.4% in 1990 (n = 22 of 26 1 total fish). In contrast, brown trout accounted for only 3% (n = 2 of 74 total fish) of the relative abundance in gill nets set in 1994 (Mongillo and Hallock 1995) and < 1% (n = 3 brown trout in 476 total fish) in gill nets set during the present study. CPUE was 0.8 brown trout/net night (8 in 10 net sets) in 1990, 0.1 brown trout/net night (2 in 21 net sets) in 1994 and < 0.1 brown trout/net night (3 in 72 net sets) in 2003. All of the brown trout collected in 2003 were collected in horizontal gill nets set along the shoreline (n = 32 sets), so CPUE was close to 0.1 brown trout/set. No brown trout were recorded in 40 vertical gill nets set in the limnetic zone in our study. No brown trout were captured in 29 vertical gill nets or 22 horizontal gill nets set in the limnetic zone during the hydroacoustic survey in 2003 (Baldwin and McLellan 2005). We also captured five brown trout by electrofishing in 2003. These data strongly suggested that brown trout were distributed predominately along the shoreline of Sullivan Lake. Their diet further reflected this distribution because the only type of identifiable fish in their stomachs was redside shiner, which were also distributed primarily along the shoreline. Kokanee, which had a more limnetic distribution, were not found in brown trout diets.

The decline in brown trout between 1980 and 2003 was attributed to the fact that the last stocking event for brown trout (n = 20,103) occurred in 1980. Brown trout apparently did not reproduce successfully in Sullivan Lake or its tributaries. No brown trout were observed during snorkel or electrofishing surveys conducted in Harvey Creek in 2003 by KNRD (Olson and Anderson 2004). Only two brown trout were captured in the Harvey Creek migration trap in 2003 (McLellan 2004) and none were observed in 2002 (McLellan 2003) or 2004 (McLellan 2005).

Ages of mountain whitefish ranged from 1 to 14. Total length and weight of each age class (mean ± SD) at time of capture were: age 1 (106 ± < 1 mm; 8 ± < 1 g), age 2 (150 ± 3 mm; 26 ± 1 g), age 3 (264 mm; 148 g), age 6 (288 ± 3 mm; 237 ± 6 g), age 8 (283 mm; 205 g) and age 14 (433 mm; 954 g). Mean backcalculated lengths at annulus formation were: 88 mm (age 1), 122 mm (age 2), 160 mm (age 3), 167 mm (age 4), 198 mm (age 5), 227 mm (age 6), 233 mm (age 7), 258 mm (age 8), 279 mm (age 9), 304 mm (age 10), 338 mm (age 11), 363 mm (age 12), 393 mm (age 13), and 413 mm (age 14). Growth of mountain whitefish was slow in comparison to other waters. For example, in Boundary/Box Canyon Reservoirs (Pend Oreille River, Washington, mountain whitefish grew respectively to 75/125 mm (age 1), 177/206 mm (age 2), 248/249 mm (age 3), 218/284 mm (age 4), 317/340 mm (age 5), 324/381 mm (age 6), 343/414 mm (age 6) and --/434 mm (age 7) (McLellan 2000/Ashe and Scholz 1992). The lower growth rates in Sullivan Lake were probably related to low productivity and the shorter growing season.

Diet of mountain whitefish (n = 8) consisted predominately of caddisflies (Trichoptera), which accounted for 97% by number, 97% by weight and 97% of the relative importance of food items found in the diet. Mountain whitefish also consumed midges (Diptera: Chironomidae), an unidentified small fish and unidentifiable insect parts. Stable isotope analysis indicated that mountain whitefish (n = 5) consumed 71% pelagically derived carbon (Smith and Black 2004). Their trophic position above copepods indicated that they fed extensively on zooplankton. Mountain whitefish abundance was similar in 1994 and 2003. CPUE was 0.14 mountain whitefish/net night in 1994 (3 in 21 net sets) (Mongillo and Hallock 1995) and 0.11 mountain whitefish/net night in 2003 (8 in 72 net sets).

One pygmy whitefish was collected in the 2003 study. It measured 116 mm TL and weighed 17 g. An additional pygmy whitefish collected in the 2003 WDFW hydroacoustic survey measured 123 mm TL. No diet information was collected for this species. Gill net surveys in 1994 and 2003 indicated that pygmy whitefish occupied primarily the limnetic zone at depths from 12 – 30 m. As previously described pygmy whitefish abundance appears to have declined markedly between 1994 and 2003. In 2003, Sullivan Lake did not appear to be the stronghold for this species it once was. Because pygmy whitefish have been identified as a species of special concern by WDFW, this situation warrants further investigation.

Burbot otoliths were extracted and sent to the WDFW fish aging lab in Olympia. Ages ranged from 2 – 14. Total length and weight of each age class (mean ± SD) at the time of capture were: age 2 (180 ± 78 mm; 42 ± 45 g), age 3 (301 ± 45 mm; 138 ± 67 g), age 4 (335 ± 29 mm; 198 ± 60 g), age 5 (342 ± 25 mm; 212 ± 40 g), age 6 (358 ± 29 mm; 173 ± 0 g), age 7 (405 ± 0 mm; 370 ± 0 g), age 8 (452 ± 42 mm; 400 ± 80 g), age 9 (431 ± 22 mm; 425 ± 98 g), age 10 (519 ± 55 mm; 905 ± 13 g), age 11 (554 ± 106 mm; 1,182 ± 782 g), age 12 (572 ± 140 mm; 1,390 ± 994 g), age 13 (674 ± 38 mm; 1,767 ± 197 g) and age 14 (740 ± 63 mm; 2,424 ± 685 g). Burbot grew more slowly but ultimately attained larger size in Sullivan Lake in comparison to other lakes in Washington. For example, burbot in Lake Chelan were 300 mm (age 4), 419 mm (age 5), 480 mm (age 6), 508 mm (age 7), 531 (age 8) mm, 531 mm (age 9), 541 mm (age 10) and those in Palmer Lake were 450 mm (age 3), 480 mm (age 4), 521 mm (age 5), 569 mm (age 6), 640 mm (age 7), 691 mm (age 8) (Bonar et al. 2000; Wydoski and Whitney 2003). Mean condition factor of burbot was 0.57 (range 0.49 – 0.63) in Sullivan Lake compared to the North American mean of 0.67 (range 0.63 – 1.22). This indicated that although burbot in Sullivan Lake attained greater total length in Sullivan Lake they were relatively scrawny. Bonar et al. (2000) noted that burbot in Washington generally grew more slowly than those from the Midwestern United States and Canadian prairie provinces.

Diet of adult burbot (n = 74) was comprised predominately of fish (52% by frequency of occurrence, 3% by number, 86% by weight and 45% of relative importance), flies/midges (14% occurrence, 83% by number, 3% by weight and 34% of the relative importance), mayflies (18% occurrence, 7.5% by number, 0.2% by weight and 8.4% of relative importance), and annelid worms (10% occurrence, 5.8% by number, 9.8% by weight and 8.4% of relative importance). Fish prey consumed by burbot included kokanee (40% of all identifiable fish prey), redside shiner (35% of identifiable fish prey) and slimy sculpin (25% of identifiable fish prey). Kokanee eggs and larvae were also consumed by burbot. Adult burbot also consumed spiders (Arachnida), scuds (Amphipods), and stoneflies (Plecoptera). During April, adult burbot were observed congregated at the mouth of Harvey Creek hiding under submerged stumps. Their stomachs contained annelids and kokanee larvae.

Stable isotope analysis of adult (n = 5) burbot, 645 – 790 mm TL (n = 5), indicated they were a top carnivore that consumed 75% limnetic carbon (Smith and Black 2004). Their trophic position above kokanee indicated that this was along a pathway from cladocera to copepods to kokanee to burbot. Piscivory by adult burbot on abundant kokanee and redside shiner was likely responsible for burbot ultimately attaining a larger size than burbot populations in other Washington lakes.

Diet of juvenile burbot (n = 16) was dominated by *Daphnia* (75% occurrence, 55% by number, 16% by weight and 32% of the relative importance), mayflies (56% occurrence, 27% by number, 61% by weight and 32% of relative importance) and amphipods (75% occurrence, 15% by number, 21% by weight and 25% of the relative importance). Juvenile burbot also consumed dipterans (flies/midges) and pouch snails (Gastropoda: Physidae).

Stable isotope analysis indicated that juvenile burbot, 115 – 129 mm TL (n = 5), consumed 36% limnetic carbon (Smith and Black 2004), which contradicted the results of the traditional stomach analysis. *Daphnia* and mayflies combined accounted for 77% of the diet by weight. These two items yielded limnetic carbon signatures in the stable isotope study. This discrepancy may be partially related to sample size differences since individual burbot were variable in their diet.

Although no pygmy whitefish were found in burbot diets during the present study, sudden expansion of gas (resulting from decreased pressure when burbot were brought up from depths of 12 – 30 meters in the limnetic zone) caused burbot to regurgitate their food, making it difficult to accurately assess their food habits. Additionally, the current low abundance of pygmy whitefish may have reduced encounters between the two species in comparison to when burbot were first introduced.

Only four slimy sculpin (32 – 60 mm TL) were collected during the 2003 surveys so no age or diet analysis was conducted. Four additional slimy sculpin (10 – 49 mm) were collected by scuba divers for the stable isotope study (Smith and Black 2004). Their trophic position indicated they were a secondary consumer of both benthic (71%) and limnetic (29%) carbon. Wydoski and Whitney (2003) reported that slimy sculpin consumed a mixed diet of snails, chironomids and caddisflies (benthic carbon sources) and zooplankton and mayflies (limnetic carbon sources in Sullivan Lake).

Based on the results of this study we recommend the following management actions:

1. Maintain the lake at its lower elevation and manage the lake for natural reproduction of adfluvial kokanee and westslope cutthroat trout. Kokanee spawning escapement should continue to be monitored through 2009 to assess cyclic dominance and trends in abundance. An investigation focusing on adfluvial westslope cutthroat trout is also recommended.
2. If a more active approach is deemed necessary, a lake fertilization project is recommended in preference to fish stocking or net pen operations because it is unlikely that the current productivity of the lake could support more fish than

are already being naturally produced. Stocking of additional fish such as rainbow trout will likely cause competition with naturally reproducing salmonids for zooplankton and aquatic insects and lead to a further decline in what are already low growth rates.

Our rationale for these recommendations is described below.

Options for lake level management include: 1) maintain the lake at a constant low elevation (780.9 m), 2) maintain the lake at a constant high level (787 m), or 3) maintain current lake drawdown operations. Biologically, the best option for Sullivan Lake would be the first option as it would improve water retention time (i.e., decrease nutrient flushing), stabilize periphyton and benthic macroinvertebrate production along shoreline areas, and maximize critical spawning habitat available for kokanee in Harvey Creek. Maintaining the lake at the high elevation would provide the same benefit for retaining nutrients and benthic production but would inundate kokanee spawning habitat in Harvey Creek, so we do not view it as a viable option. [Data collected in 2003 indicated that the majority of kokanee spawning occurs in Harvey Creek and lakeshore spawning is minimal owing to poor substrate, so it is necessary to protect the spawning habitat in Harvey Creek.] We recognize that, if option 1 is adopted, water that is currently stored in Sullivan Lake will not be available to generate hydroelectric power at 14 dams along Pend Oreille and Columbia Rivers.

The primary factor limiting biological production in Sullivan Lake was low nutrient inputs. Low nutrient levels resulted in minimal fertilization of phytoplankton. Low levels of phytoplankton limited secondary production in Sullivan Lake as indicated by low diversity, density and size of zooplankton and benthic macroinvertebrates in comparison to other oligotrophic lakes. Low secondary production limited fish production. Therefore, one option to increase fish production in Sullivan Lake would be to fertilize it with nitrogen and phosphorus.

Lake fertilization has been used successfully to increase phytoplankton, zooplankton and benthic macroinvertebrate production, and increase yields of salmon or trout in oligotrophic lakes in Alaska and British Columbia. For example, in Kootenay Lake, British Columbia, kokanee salmon stocks declined after Libby Dam, constructed upstream of Kootenay Lake, trapped nutrients flowing down the Kootenai River in the sediments of its reservoir (Lake Koocanusa). Fewer nutrients flushing down the Kootenai River resulted in declines of phytoplankton, zooplankton and kokanee salmon in Kootenay Lake (Ashley et al. 1997). Although Kootenay Lake was a naturally oligotrophic lake, it was made more oligotrophic by human actions (i.e., construction of Libby Dam). Hence, Kootenay Lake can be considered to be ‘culturally oligotrophic.’ Subsequently, 47.1 tons of phosphorus and 206.7 tons of nitrogen were used to fertilize the North Arm commencing in 1992. This increased phytoplankton, zooplankton and kokanee abundance in Kootenay Lake (Ashley et al. 1997). Prior to nutrient enrichment kokanee abundance had declined from about 35 million kokanee (pre- Libby Dam) to a low in 1991 and 1992 of about 7 million kokanee. Spawning escapement of kokanee into Meadow Creek and the Lardeau River totaled about 270,000 adult kokanee in 1991 and

1992. After 10 years of fertilization, in 2002, kokanee abundance had increased to 35 million. Spawning escapment into Meadow Creek and the Lardeau River totaled 2 million adult kokanee.

It should be emphasized that Sullivan Lake is a naturally oligotrophic lake not a culturally oligotrophic lake like Kootenay Lake. Kootenay Lake was made oligotrophic by human activities (construction of Libby Dam in Montana as explained above). In Kootenay Lake, fertilization added back nutrients that had been lost whereas in Sullivan Lake fertilization would add nutrients above natural levels.

Disadvantages of lake fertilization in oligotrophic lakes are less studied than benefits. Addition of fertilizer into the water column may fertilize phytoplankton at the expense of periphyton. In one study, adding nutrients increased phytoplankton to the point where they reduced light penetration and shaded out periphyton (Vadeboncoeur et al. 2001). In many lakes, periphyton account for about 50% of a lake's total primary production (Lodge et al. 1998). Hence, species of fish (e.g., cutthroat trout) that are more dependent upon aquatic insects that graze on periphyton might be harmed at the same time planktivorous species (e.g., kokanee), benefit from water column fertilization. Because of potential unforeseen consequences such as this we do not recommend fertilization at the present time.

We recommend that a nutrient loading study be performed prior to any addition of fertilizers at Sullivan Lake. Elements of this study should include: 1) measuring nutrient inputs around the lake, including ground water inputs which are usually absorbed by periphyton before they can be assimilated by phytoplankton; 2) measuring nutrients lost due to outflow; and 3) measuring nutrients retained in the lake that would be available for recycling during turnover periods. These data would determine the sources (e.g., surface water, ground water) and amounts of nutrients currently available for biological production in Sullivan Lake, and establish a baseline for determination of the amounts of nutrients that could be added. In turn, specific amounts of nutrients that would be needed to increase production could be determined. These studies will be very expensive, costing on the order of $100,000 - $200,000.

We advise against additional stocking of salmonids (especially rainbow or cutthroat trout, or kokanee salmon) either via direct planting or into net pens. Food habit studies indicated significant diet overlap between rainbow trout and naturally produced cutthroat trout and kokanee. It is probable that stocking more rainbow trout would increase competition and lead to reduced growth in both stocked and wild fish because there is a finite amount of food in Sullivan Lake. Rainbow trout can also hybridize with native westslope cutthroat trout, resulting in introgression of their alien genes into the locally adapted cutthroat genome. Apparently, introgression has so far not occurred between rainbow trout and cutthroat trout in Sullivan Lake (Trotter 2001), but in the Flathead River system, Montana, hybridization between rainbow trout and westslope cutthroat trout was evident at 24 of 42 sampled sites (Hitt et al. 2003).

The advantage of net pens over direct stocking is that fish in the net pens are fed processed food until they attain legal size for harvest, so they do not consume so much of the natural food supply in a lake. Net pens were used successfully to enhance the rainbow trout fishery on Lake Roosevelt where there was an abundant supply of large *Daphnia* sp. (> 1.5 mm). Net pen rainbow trout in Lake Roosevelt grew at a rate of about 25 – 37 mm (1 –1.5 inches) per month after release into the lake by consuming *Daphnia*. Their rapid attainment of large size made them popular with anglers. Net pens will probably not work so well in Sullivan Lake because the forage base is very limited and the size of *Daphnia* was small (< 0.75 mm).

EPA reported that for every ton of fish produced in net pen aquaculture, a ton of fecal waste is also produced. In Lake Roosevelt, such contamination by net pens did not pose a problem because the reservoir has a fast flushing rate (water retention time usually 32 – 53 days, range 17 – 120 days) (McLellan et al. 2003). In Sullivan Lake, the flushing rate is much slower (1.4 – 37 years) so there is more potential for contamination. Since diseases are transferred through fish populations more easily when they are confined and crowded than swimming freely in the wild, net pens also have the potential to introduce disease into Sullivan Lake.

Cutthroat trout stocking or net pens should be discouraged for similar reasons listed for rainbow trout. Planting more kokanee should be discouraged because natural reproduction of kokanee in Sullivan Lake already uses all of the available food resources. Further stocking will make more kokanee mouths to feed, cause competition with naturally produced kokanee and result in smaller-sized kokanee.

If fish plants or net pens are deemed necessary by fisheries agencies, we believe that brown trout in limited numbers (1000 – 1400 individuals annually) is the best option for stocking in Sullivan Lake. Brown trout grow to trophy size in Sullivan Lake as a result of an abundant food resource (redside shiner). Annual stocking at low densites (1 brown trout per surface acre) would promote rapid growth to trophy size and afford protection to the redside shiner prey base. Brown trout should be released at a catchable size range (8 inches), when they are more likely to be piscivorous, to reduce competition with wild salmonids for invertebrate prey. Predation by brown trout on native salmonids (especially pygmy whitefish) is a matter of concern but brown trout have existed in Sullivan Lake for many years apparently in balance with kokanee, cutthroat trout and pygmy whitefish. In the present study brown trout ate exclusively redside shiner but the number of brown trout stomachs sampled was low (n = 8). Since brown trout did not appear to spawn in the Sullivan Lake/Harvey Creek system for the past several years, if they pose an unforeseen threat to native salmonids in the future, the threat could be corrected by cessation of stocking. Trophy sized brown trout, even in low numbers, would probably attract anglers and promote the local economy. Tiger trout, a sterile hybrid between brown trout and brook trout, could possibly be used in place of brown trout. However, little is known about their food habits in eastern Washington lakes, so it is unknown if they will prey on the same food as brown trout and attain a size that would attract anglers.

We recommend conducting a winter creel survey to determine burbot harvest and using that information to establish fishing regulations that keep burbot populations in check since they might impact native pygmy whitefish. In April 2003, burbot congregated in stumps and root wads off the mouth of Harvey Creek to feed on adfluvial outmigrant kokanee. A remotely operated vehicle (ROV) video system could be used to investigate burbot consumption of kokanee and possibly pygmy whitefish which are also known to utilize Harvey Creek.

Pygmy whitefish is listed as a species of special concern in Washington State due to limited distribution and low abundance. Sullivan Lake was a stronghold for pygmy whitefish as recently as 1994 (Mongillo and Hallock 1995). As the present study indicated that Sullivan Lake is no longer a stronghold for pygmy whitefish, we recommend that a study be performed that focuses on assessment of the current status of pygmy whitefish. An effort should be made to duplicate the timing and sampling gear used by Mongillo and Hallock (1995). These data should be compared with the 1994 survey to assess trends in pygmy whitefish populations.

We recommend that a study be initiated to determine the extent of entrainment of nutrients, phytoplankton, and zooplankton during drawdowns. Quantification of the magnitude of these entrainment losses would help to justify or refute the need for changes in current reservoir operations.

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